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Radio and X-ray emission from disc winds in radio-quiet quasars

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ABSTRACT
It has been proposed that the radio spectra of radio-quiet quasars is produced by free-free emission in the optically thin part of an accretion disc wind. An important observational constraint on this model is the observed X-ray luminosity. We investigate this constraint using a sample of PG radio-quiet quasars for which XMM-*Newton* EPIC spectra are available. Comparing the predicted and measured luminosities for 0.5, 2 and 5 keV, we conclude that all of the studied PG quasars require a large hydrogen column density absorber, requiring these quasars to be close to or Compton-thick. Such a large column density can be directly excluded for PG 0050+124, for which a high-resolution RGS spectrum exists. Further constraint on the column density for a further 19 out of the 21 studied PG quasars comes from the EPIC spectrum characteristics such as hard X-ray power-law photon index and the equivalent width of the Fe Kα line; and the small equivalent width of the C IV absorber present in UV spectra. For 2 sources: PG 1001+054 and PG 1411+442 we cannot exclude that they are indeed Compton-thick, and the radio and X-ray luminosity are due to a wind originating close to the super-massive black hole. We conclude that for 20 out of 22 PG quasars studied free-free emission from a wind emanating from the accretion disc cannot mutually explain the observed radio and X-ray luminosity.

1 INTRODUCTION

Currently, the origin of the nuclear radio emission from radio-quiet quasars (RQQs), which consists of 90% of the optically detected quasars (Ivezić et al. 2002), is not understood. The luminosity of the nuclear radio emission and its compactness is similar to the nuclear radio luminosity, brightness temperature and compactness of radio-loud quasars (Blundell & Beasley 1998; Ulvestad, Antonucci & Barvainis 2005). Likewise the variability (Barvainis et al. 2005) is similar between both classes. For radio-loud quasar the nuclear radio emission is explained by the superposition of different jet-components (Cotton et al. 1980). However, radio-quiet quasars lack radio emission on large scales which are indicative of expanding lobes fed by jets. A possibility is that radio-quiet quasars do have much weaker jets, which do not escape the inner 1 kpc of the host galaxy (Miller, Rawlings & Saunders 1993; Kuncic 1999). However most RQQs studied with VBLI show unresolved radio emission, even at mas scales, indicating an emission volume of a few pc^3 (Blundell & Beasley 1998; Ulvestad, Antonucci & Barvainis 2005). Therefore, the suggestion that the radio emission from nuclei in RQQ is due to a superposition of jet knots, seems unrealistic for those RQQ where there is no evidence for a jet.

Recently, two alternative models explaining the radio emission in RQQs have been proposed. Blundell & Kuncic (2007) proposed that radio emission in radio-quiet quasars originates in a optically thin plasma with a temperature of order 10^7 K, such that the plasma is completely ionised. This plasma has a density high enough that free-free processes dominate. Such a plasma can explain the observed brightness temperature of the nuclei of RQQs, if the optical depth is close to unity. This model explains the flat radio spectra observed in quasars. The authors assume that the wind is launched from the accretion disc at a radius $\approx 10^{-3}$ pc, and becomes optically thin at a photospheric radius of 0.1−1 pc. In this model the mass-loss rates in these winds are significant, and these winds could have an effect on the feedback processes operating in the host galaxy.

An alternative model was proposed by Laor & Behar (2008), who model the radio and X-ray emission as due to coronal emission, similar to coronal emission observed in stars. They base this model on the observation that there is a rather tight correlation between the radio and X-ray luminosity: $L_{\rm R} \sim 10^{-5} L_{\rm X}$, similar to the Güdel-Benz relation for coronally active stars. For coronally active stars it has been shown that this relation is due to magnetic heating of the corona. Laor & Behar (2008) therefore propose that the radio and X-ray emission from the nuclei of RQQs is due to magnetic heating of the corona, presumed to be located above the accretion disc. As with the optically thin wind model, the predicted spectrum at a few GHz is flat.

In this paper we test the optically thin wind model as proposed by Blundell & Kuncic (2007). For an optically thin wind one can predict the X-ray luminosity for a given radio luminosity. One can then compare the predicted X-ray luminosity to the measured X-ray luminosity. The wind model overpredicts the soft X-ray luminosity (Laor & Behar 2008), unless intervening absorbing material is present in the outflow. The absorption could arise from a radiatively cooled part of the wind further from the accretion disc. The X-ray continuum is generally well fit by a power-law and a (modified) black body at soft energies. The black body fits the soft

excess emission probably from the accretion disc or due to ionised reflection. The power-law component is generally assumed to be Comptonised emission from the corona located somewhere close to the accretion disc. Alternatively, a good fit can be obtained with a broken power-law with a break energy at ~1.5 keV.

X-ray absorbing outflows (see Crenshaw, Kraemer & George 2003 for a review), are especially well studied in Seyfert 1 galaxies, due to their X-ray brightness, which allows for high-resolution X-ray spectroscopy. Generally the absorption consists of 2 or more ionisation components, spanning a range in ionisation parameter of 3 or more orders of magnitude, and have outflow velocities similar to those measured at UV wavelengths of $v_{\rm w}\sim$ 100 – 1000 km s^{-1} (Kaastra et al. 2000; Kaspi et al. 2001; Kaastra et al. 2002). This outflowing gas absorbs the continuum and produces line and edge absorption, allowing for their kinematics to be studied. Warm absorbers have been detected in more than 50% of Seyfert 1 galaxies (Crenshaw, Kraemer & George 2003; Reynolds 1997; George et al. 1998). A similar fraction of RQQs might have a warm absorber (Porquet et al. 2004; Piconcelli et al. 2005, but see also Brocksopp et al. 2006).

The exact location of the absorbing gas, even in the well studied Seyfert 1 galaxies, as well as its origin, are still not well constrained (Steenbrugge et al. 2009; Gabel et al. 2005), and two origins have been proposed. The absorbing outflows are thought to originate either from the accretion disc (e.g. Murray & Chiang 1995; Murray et al. 1995; Elvis 2000; Proga, Stone & Kallman 2000; Everett & Murray 2007), or from the molecular torus (e.g. Krolik & Kriss 2001; Ashton et al. 2004; Blustin et al. 2005). Similarly, the ionisation structure of the absorber is still poorly constrained, and can currently be well fit with several discrete ionisation components, modelling photoionised clumps (e.g. Arav et al. 2005; Krolik & Kriss 2001; Różańska et al. 2006) or a continuous ionisation structure (e.g. Steenbrugge et al. 2005; Behar 2009). The total X-ray observed hydrogen column density in Seyfert 1 galaxies spans at least 2 orders of magnitude, from 4.9×10^{24} m^{-2} in Mrk 279 (Ebrero et al. 2010) to 3.8×10^{26} m^{-2} in NGC 3783 (Chelouche & Netzer 2005).

Approximately 22% of optically detected quasars exhibit large hydrogen absorbing column densities, the broad absorption line (BAL) quasars (Hewett & Foltz 2003). The total column density derived from UV observations is ~5×10^{27} m^{-2} (Krolik 1999), while Blustin et al. (2008) find an average X-ray total column density of 2×10^{28} m^{-2}. It is currently unknown whether the detection of these broad absorption lines is due to orientation (Weymann et al. 1991), or whether BALQSOs are an evolutionary phase of QSOs (Briggs, Turnshek & Wolfe 1984).

This paper is organised as follows. Section 2 summarises the bremsstrahlung disc wind model for radio emission and the associated X-ray luminosity predicted by this model. We also show that this wind can radiatively cool and form an absorber. In the following section we describe the sample we use and compare the predicted and measured X-ray luminosities. In Section 4 we model the required absorption to explain the difference between the predicted and measured X-ray luminosity. In Section 5 we show that absorption cannot be the origin of the difference between predicted and measured X-ray luminosity, with the exception of PG 1001+054 and PG 1411+442. Our conclusions are given in Section 6.

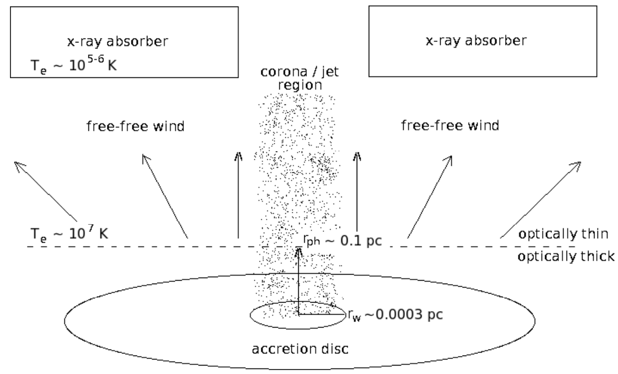


Figure 1. Schematic illustration of the disc wind and X-ray absorber (not to scale). $r_{\rm w}$ is the characteristic radius at which the free-free wind is launched from the disc, $r_{\rm ph}$ is the distance at which the wind becomes transparent to free-free absorption, and $T_{\rm e}$ is the electron temperature.

2 DISC WIND EMISSION AND ABSORPTION

2.1 Emission model

Following Blundell & Kuncic (2007), we consider a thermal accretion disc wind at radii $r \gtrsim r_{\rm w}$, where $r_{\rm w}$ is the launching radius of the wind. A hot disc wind that is optically-thin to both electron scattering and free-free absorption can exist beyond a photospheric radius $r_{\rm ph} \simeq 0.1 - 1\,$pc. In this part of the wind, with mass outflow rate $\dot{M}_{\rm w}$, the specific bremsstrahlung luminosity is

$$L_\nu = 7.8\times10^9 \bar{g}_{\rm ff} f_\Omega^{-1} r_{\rm ph}^{-1} T_{\rm e}^{-1/2} \exp(-h\nu/kT_{\rm e}) \dot{M}_{\rm w}^2 v_{\rm w}^{-2} \;\;{\rm erg\,s^{-1}} \qquad (1)$$

where $f_\Omega = \Omega/4\pi \lesssim 1$ is the geometrical covering factor of the outflow, $v_{\rm w}$ is the outflow velocity at radius $r_{\rm w}$ and $\bar{g}_{\rm ff}$ is the velocity averaged free-free Gaunt factor (Rybicki & Lightman 1979). At radio frequencies, $\bar{g}_{\rm ff} \simeq 10$ and at X-ray energies, $\bar{g}_{\rm ff} \simeq 1$. A schematic illustration of the model is presented in Fig. 1.

Assuming the radio and X-ray emission are produced by the same mechanism from the same source, eq. 1 also applies at X-ray energies. The expected X-ray luminosity is thus:

$$L_\nu \approx \frac{L_\nu}{10} \exp\left(-\frac{h\nu_X}{kT_e}\right) \qquad (2)$$

where the factor 1/10 is the ratio of the Gaunt factors at these energies, and we ignore the exponential factor at the radio frequency, as it is negligible. We will use this formula to predict the X-ray luminosity at 0.5, 2 and 5 keV.

2.2 Absorption model

Considering that the X-ray luminosity is over-predicted in this model (Laor & Behar 2008), we here describe a model of how the hot optically thin wind can cool to produce an absorber and derive that the required density is within a reasonable range.

Outflowing diffuse gas can radiatively cool to produce the absorber observed in Seyfert 1 galaxies and RQQs provided that the radiative cooling timescale $t_{\rm c}$ is much less than the dynamical cooling timescale $t_{\rm dyn}$:

$$t_{\rm c} \ll t_{\rm dyn} = \frac{R}{v_{\rm w}} \qquad (3)$$

The bremsstrahlung cooling time can be expressed as

$$t_{\rm c} = 1.0 \times 10^{-12} f_\Omega r_{\rm w}^2 \bar{g}_{\rm b}^{-1} T_{\rm e}^{1/2} v_{\rm w} / \dot{M}_{\rm w} \ \ {\rm s} \quad (4)$$

where $\bar{g}_{\rm b} \simeq 1.2$ is the frequency-averaged Gaunt factor, and $T_{\rm e} = 10^7$ K is the temperature of the emitting plasma near the wind photosphere. For canonical parameters, we use the values $v_{\rm w} = 500$ km s^{-1}, $r_{\rm w} = 10^{15}$ cm, $f_\Omega = 0.1$, and $R = r_{\rm ph} = 0.1$ pc (Blundell & Kuncic 2007). Eqs. 3 and 4 imply that the wind mass-loss rate must satisfy

$$\dot{M}_{\rm w} \gg 4 \times 10^{-10} \ \ M_\odot\,{\rm yr}^{-1} \quad (5)$$

in order for the gas to radiatively cool on a timescale shorter than the dynamical timescale.

At the base of the disc wind, the electron number density $n_{\rm e}$ can be related to the mass outflow rate using the continuity equation,

$$\dot{M}_{\rm w} = 2\pi f_\Omega r_{\rm w}^2 v_{\rm w} m_{\rm p} n_{\rm e} \simeq 8 \times 10^{-13} n_{\rm e} \ \ M_\odot\,{\rm yr}^{-1} \quad (6)$$

which, even for a rarefied wind with $n_{\rm e} \simeq 10^5$ cm^{-3}, clearly satisfies Eq. 5. Hence, the emitting outflow from the disc wind can cool and form a partially ionised absorber as observed in a few RQQs and about half of Seyfert 1 galaxies.

3 DATA

A useful sample of optically-selected radio-quiet quasars is the Palomar-Green (PG) Bright Quasar Survey (Schmidt & Green 1983). Our sample of PG quasars is dictated by the need of good medium-resolution EPIC XMM-*Newton* data or high signal-to-noise high-resolution X-ray spectra. We therefore chose to use the RQQs in the sample of PG quasars which were studied in detail by Brocksopp et al. (2006) and added PG 0050+124 which has a high-signal-to noise XMM-*Newton* RGS spectrum (Costantini et al. 2008), PG 0844+349 and PG 2214+139. PG 0844+349 was studied in detail by Brinkmann et al. (2006) and Gallo et al. (2010) and PG 2214+139 by Piconcelli et al. (2004). This gives us a sample of 22 RQQs. For this subset of PG quasars we utilise the 5 GHz radio luminosities compiled by Laor & Behar (2008) which are based on observations with the Very Large Array by Kellermann et al. (1989) and Kellermann et al. (1994). The studied PG quasars all have a redshift $z < 0.5$ (Boroson & Green 1992). In this sample, 3 have measured UV C IV equivalent line widths greater than 1 Å (Laor & Behar 2008), which suggests the soft X-ray band is likely to be affected by X-ray absorption. These are : PG 1001+054, PG 114+445 and PG 1411+442. The final quasar sample is given in Table 1, which lists the redshift, the 5 GHz radio and the 2−5 and 0.3−10 keV X-ray luminosity.

Table 1. Properties of the PG quasars studied in this paper. The redshifts and radio νL_ν data is taken from Laor & Behar (2008), the X-ray νL_ν for the 2−5 and 0.3−10 keV band is taken from Brocksopp et al. (2006). For PG 0050+124, we use the unabsorbed 0.5−2 keV luminosity determined from the RGS spectra (Costantini et al. 2008). For PG 0844+349 we use the 2−10 and 0.5−2 keV luminosities for the 2001 high flux state as given by Gallo et al. (2010), and for PG 2214+139 we list the 0.5−2 and 2−10 keV luminosity given by Piconcelli et al. (2004).

name	redshift	νL_R^a 5 GHz	νL_X^b 2−5 keV	νL_X^b 0.3−10 keV
PG 0050+124	0.0587	9.33	–	0.7^c
PG 0844+349	0.0644	0.65	0.7^d	1^c
PG 0947+396	0.2059	11.7	1.18	5.4
PG 0953+414	0.2341	95.5	2.89	15.7
PG 1001+054	0.1610	24.0	0.025	0.1
PG 1048+342	0.1667	<4.07	0.55	2
PG 1114+445	0.1438	4.47	0.57	$–^e$
PG 1115+407	0.1542	4.47	0.5	3.3
PG 1116+215	0.1765	158.5	1.79	10.3
PG 1202+281	0.1654	5.49	1.36	5.5
PG 1216+069	0.3318	416.9	2.14	2.3
PG 1322+659	0.1676	6.31	0.64	4.3
PG 1352+183	0.1508	5.75	0.66	3.5
PG 1402+261	0.1643	18.6	0.82	5.4
PG 1411+442	0.0897	3.16	0.02	1.2
PG 1415+451	0.1133	3.16	0.21	1.2
PG 1427+480	0.2203	<7.59	0.89	4.3
PG 1440+356	0.0777	8.71	0.26	2.2
PG 1444+407	0.2676	<9.77	0.76	5.2
PG 1543+489	0.4009	27.5	0.71	4.6
PG 1626+554	0.1317	3.31	0.85	3.6
PG 2214+139	0.0657	1.07	0.48^d	0.39^c

[a] The units are 10^{31} W.
[b] The units are 10^{37} W.
[c] This is the 0.5−2 keV unabsorbed luminosity.
[d] This is the 2−10 keV unabsorbed luminosity.
[e] This value is not given as the broken power-law model did not yield a good fit.

We predict the X-ray luminosity of these PG quasars at 0.5, 2 and 5 keV (see Table 2). These energies were chosen so as to sample part of the soft X-ray emission that is heavily affected by absorption, as well as part of the hard X-ray emission, that is much less affected. Any serious over-prediction of the 5 keV luminosity would indicate that the absorber is close to or Compton-thick. In the soft X-ray band, part of the emission might come directly from the accretion disc, the so-called soft excess, and thus the difference between predicted and measured X-ray luminosity is a lower limit, barring X-ray variability that is larger than the soft excess emission. Therefore, in modelling the absorption necessary to equate the predicted and measured X-ray luminosity we will focus on the 2 and 5 keV data. The hard X-ray band is well modelled by a simple power-law model. This power-law component is generally believed to be due to Compton scattering of accretion disc photons. The contribution from a reflection component should be small to negligible at 2 and 5 keV. At higher energies, the reflection component becomes larger, therefore we will not compare the predicted and measured 10 keV luminosity.

We note that the radio and X-ray luminosities were determined with a difference in time of about 15 years. The X-ray luminosity is known to be variable and this will cause a scatter in the relationship between predicted and measured X-ray luminosity. The X-ray luminosity variability of Seyfert 1 galaxies depends on the mass of the central black hole, with lower mass objects generally being more variable, and on shorter timescales (Uttley, McHardy & Papadakis 2002; McHardy et al. 2004). For the PG quasars studied here, the black hole masses have been determined with a variety of methods and range between 2×10^7 M$_\odot$ (PG 1440+356) and 2×10^9 M$_\odot$ (PG 1425+267) (Brocksopp et al. 2006), and on average are larger than the well studied Seyfert 1 galaxies. Seyfert 1 galaxies are known to have an "off" state, where the luminosity is about an order of a magnitude lower. However, these off-states are rather rare occurrences, and we would not expect more than 2 of the studied PG quasars to be in such a state.

Therefore, luminosity variability cannot explain a systematic over-prediction of the X-ray luminosity.

To compare to the observed luminosities, which reported as νL_ν, we afterwards multiplied the predicted luminosity by the corresponding frequency of the emission. For the rest of the paper the luminosities quoted are νL_ν. Brocksopp et al. (2006) modelled the 2−5 keV spectrum with a simple power-law model with Galactic absorption, which gave a good fit to this part of the spectrum. However, this fit was inadequate to fit the whole 0.3−10 keV spectrum. To fit the whole energy range they used a broken power-law model with Galactic absorption, listing in their table 3, the 2 photon indices, the break energy, the 0.3−10 keV luminosity and the column density, or upper limit, for a neutral absorber presumed part of the quasar.

Due to the listed model parameters we can calculate the observed 0.5 (0.4−0.6), 2 (1.9−2.1) and 5 (4.9−5.1) keV luminosity, which can be directly compared to the 0.5, 2 and 5 keV predicted luminosities. Because the information about the spectral model of the X-ray data is not given by Laor & Behar (2008) or the references they refer to, this was not possible for the complete set studied by them. Considering the range of power-law photon indices determined by Brocksopp et al. (2006), between 0.34 and 2.54, correcting the 0.2−1 keV luminosity (Behar, priv. comm. 2010) given by Laor & Behar (2008) to either the 0.5 or 2 keV luminosity will result in ambiguous results, and is the main reason we use a smaller sample in this study.

To be specific, we used the 2−5 keV luminosity with the simple power-law model to calculate the 2 and 5 keV luminosity using SPEX[1]. To calculate the 0.5 keV νL_ν we used the broken power-law model and the 0.3−10 keV νL_ν given by Brocksopp et al. (2006). For PG 0050+124, PG 0844+349 and PG 2214+139 we use the continuum model and parameters provided by Costantini et al. (2008); Gallo et al. (2010); Piconcelli et al. (2004). Table 2 lists the predicted X-ray luminosities as well as the 0.5, 2 and 5 keV luminosity calculated from the spectral models and parameters. For these 3 energies the predicted luminosity is larger than the measured one, over-predicting the measured luminosity by factors ranging from 2.8 and 2.2×10^4. Table 2 lists the differences between the predicted and measured 0.5, 2 and 5 keV luminosity in log values.

For type 1 quasars, which have moderate or no absorption, if the difference between predicted and measured νL_ν is due to absorption, then one expects that the difference to be largest for 0.5 keV and smallest for 5 keV. For the moderate column densities or upper limits listed by Brocksopp et al. (2006), one would expect that these PG quasars are indeed all type 1 (but see later for the 2 possible exceptions). Absorption, both neutral and ionised, affects mostly the soft X-ray band and if moderate should become negligible above 2 keV. This is clearly not observed from Table 2: the difference between predicted and measured νL_ν (in log) at 2 keV is larger than for 0.5 keV, and thus certainly not negligible. A likely explanation for why the luminosity difference is larger, is the soft excess emission which we sample at 0.5 keV but not at 2 keV. On average in both bands the difference between predicted and measured luminosity is more than 2 orders of magnitude. The difference between predicted and measured νL_ν at 5 keV, which is least affected by absorption, is smaller but still significant. Figs. 2, 3 and 4 show the measured versus the predicted X-ray luminosity for 0.5, 2 and 5 keV.

[1] http://www.sron.nl/spex

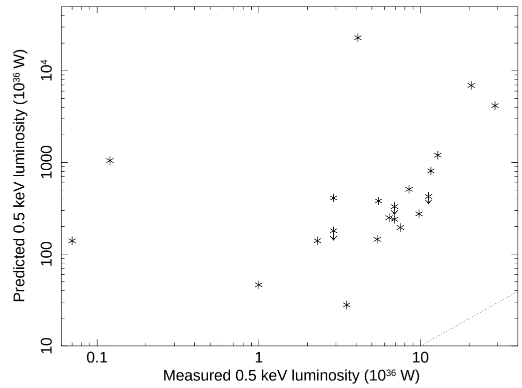


Figure 2. Predicted bremsstrahlung luminosity and measured luminosity at 0.5 keV for the PG quasars studied. The dotted line indicates where these values are equal.

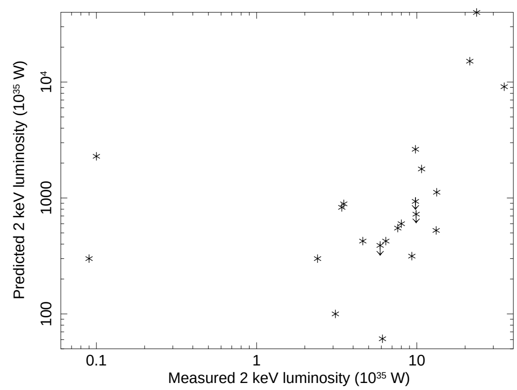


Figure 3. Same as Fig. 2, but for 2 keV.

4 X-RAY ABSORPTION

The optical depth needed for the predicted X-ray luminosity L_ν to match that observed $L_{\nu,\rm obs}$ is

$$\tau = N_{\rm H}\sigma = \ln\left(\frac{L_\nu}{L_{\nu,\rm obs}}\right) \qquad (7)$$

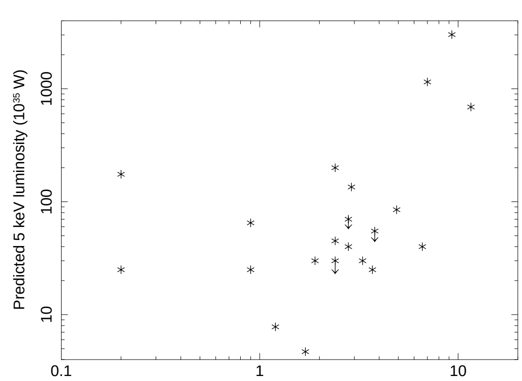


Figure 4. Same as Fig. 2 but for 5 keV.

Table 2. List of measured and predicted X-ray monochromatic luminosity, νL_ν using eq. 2 at 0.5, 2 and 5 keV. Also listed is the difference between predicted and measured X-ray luminosity in log, as well as the difference in measured luminosity for the neutral absorber column density quoted by Brocksopp et al. (2006). The last four columns list the hydrogen column density of a neutral and ionised (logξ = 1.5) absorber needed to equate the measured and predicted 2 and 5 keV luminosity. For PG 0050+124, PG 1001+054, PG 1114+445,PG 1411+442 and PG 2214+139, we used the detailed warm absorber models to model the neutral and ionised column density listed in the last 2 columns.

	calculated			predicted			difference							
name	$\nu L^a_{0.5}$	νL^b_2	νL^b_5	$\nu L^a_{0.5}$	νL^b_2	νL^b_5	$\nu L_{0.5}$	νL_2	νL_5	abs. νL^c_5	$N^d_{H,n,2}$	$N^d_{H,i,2}$	$N^d_{H,n,5}$	$N^d_{H,i,5}$
PG 0050+124	2.9	3.5	–	410	890	–	2.1	2.4	–	–	0.13	0.26	–	–
PG 0844+349	3.5	6.1	1.7	28	61	4.7	0.9	1.0	0.44	–	0.05	0.11	0.28	0.32
PG 0947+396	8.5	13.3	4.9	510	1120	85	1.8	1.9	1.2	<0.9	0.10	0.20	0.74	0.9
PG 0953+414	28.9	35.1	11.6	4170	9120	690	2.2	2.4	1.8	<2.3	0.13	0.26	1.15	1.3
PG 1001+054	0.12	0.1	0.2	1050	2290	175	3.9	4.3	2.9	<4.8	0.2	0.41	1.3	1.3
PG 1048+342	2.9	5.9	2.4	<180	<390	<30	<1.8	<1.8	<1.1	<2.5	<0.1	<0.2	<0.7	<0.8
PG 1114+445	–	4.6	3.3	195	425	30	–	2.0	1.0	–	0.09	0.19	0.25	0.75
PG 1115+407	7.5	6.4	1.9	195	425	30	1.4	1.8	1.2	<4.4	0.10	0.19	0.75	0.85
PG 1116+215	20.6	21.4	7.0	6920	15135	1150	2.5	2.8	2.2	<2.6	0.15	0.31	1.45	1.6
PG 1202+281	6.9	13.2	6.6	240	525	40	1.5	1.6	0.8	<0.8	0.09	0.17	0.5	0.6
PG 1216+069	4.1	23.6	9.3	22910	39810	3020	3.7	3.2	2.5	6.5	0.17	0.35	1.65	1.8
PG 1322+659	9.8	8.0	2.4	275	600	45	1.4	1.9	1.3	<4.4	0.10	0.21	0.85	0.95
PG 1352+183	6.4	7.6	2.8	250	550	40	1.6	1.9	1.2	<0.8	0.1	0.21	0.8	0.85
PG 1402+261	11.6	10.7	2.9	810	1780	135	1.8	2.2	1.7	<2.0	0.12	0.24	1.1	1.25
PG 1411+442	0.07	0.09	0.2	140	300	25	3.2	3.5	2.1	<0.03	0	0	1.77	1.5
PG 1415+451	2.3	2.4	0.9	140	300	25	1.8	2.1	1.4	<1.4	0.11	0.23	0.9	1
PG 1427+480	6.9	9.9	3.8	<330	<725	<55	<1.7	<1.9	<1.2	<1.9	<0.10	<0.21	<0.8	<0.9
PG 1440+356	5.5	3.4	0.9	380	830	65	1.8	2.4	1.8	1.8	0.13	0.26	1.2	1.3
PG 1444+407	11.2	9.8	2.8	<425	<935	<70	<1.6	<2.0	<1.4	<2.2	<0.11	<0.22	<0.9	<1
PG 1543+489	12.8	9.8	2.4	1200	2630	200	2.0	2.4	1.9	<49	0.13	0.26	1.25	1.4
PG 1626+554	5.4	9.3	3.7	145	315	25	1.4	1.5	0.8	<3.3	0.08	0.16	0.5	0.6
PG 2214+139	1.0	3.1	1.2	46.3	100	7.8	1.7	1.5	0.8	–	0.08	0.17	0.5	0.6

[a] The units are 10^{36} W.
[b] The units are 10^{35} W.
[c] This is in 10^{-4}.
[d] The units are 10^{28} m^{-2}.

where N_H is the absorbing hydrogen column density and σ is the atomic cross section. The ionisation parameter is (Tarter, Tucker & Salpeter 1969)

$$\xi = \frac{L}{n_H r^2} \tag{8}$$

where L is the 1−1000 Rydberg luminosity, n_H is the hydrogen density of the illuminated gas, and r is the distance of the absorber from the ionising source, presumed to be the inner accretion disc. The ionisation parameter in the well studied Seyfert 1 galaxies covers a large range: $0.1 < \xi < 10^4$, with multiple ionisation parameters needed to adequately model the absorber (Steenbrugge et al. 2003, 2005; Costantini et al. 2007; Holczer, Behar & Kaspi 2007; Behar 2009).

To test whether absorption is causing the difference between the predicted and measured X-ray luminosity, we modelled with SPEX the luminosity difference at 5 keV caused by a neutral absorber which has a column density listed in table 3 of Brocksopp et al. (2006). For the neutral absorber we used the *abs* model, while we used the *xabs* model for an ionised absorber. The *abs* model uses the McCammon & Sanders (1990) cross-sections for a neutral absorber. *xabs* calculates the continuum and line absorption in a self-consistent fashion for all the ions for a given ionisation parameters. The depth of the absorption is then scaled with the hydrogen column density. We assumed solar abundances given by Anders & Grevesse (1989).

For those PG quasars where only an upper limit to the column density is listed, we used this upper limit. We used the photon index given for the simple power-law model in our modelling, similar to how we determined the 5 keV measured luminosity. The resulting difference in luminosities is, as expected, very small, on average (in log) 0.0005, and much smaller than the difference between predicted and measured luminosity at 5 keV. As for most PG quasars Brocksopp et al. (2006) gives only upper limits, the real difference in luminosity due to absorption should be even smaller. Therefore, either the model, i.e. the fact that the radio and X-ray emission arise from a wind, is wrong, or the absorption in these systems is severely underestimated by Brocksopp et al. (2006). The latter is possible if the broken power-law model, which fits the soft excess also fits the absorption. For absorbed sources one expects that the soft X-ray photon index is flatter than the hard X-ray photon index due to absorption. This is not the case, but this could be due to a differing shape of the soft excess in these sources compared to the soft excess in Seyfert 1 galaxies.

There is one PG quasar that has a high-resolution reflection grating spectrometer (RGS) spectrum available and which is listed by Laor and Behar, PG 0050+124 (also known as IZwicky 1), we therefore include it in our sample. The spectrum is well modelled by a 2 component warm absorber with log($\xi/10^{-9}$ Wm) = 0 and 2.6 and a $N_H = 13.3\times10^{24}$ and 13.5×10^{24} m^{-2}, respectively (Costantini et al. 2008). These authors also list the unabsorbed (i.e. correcting the measured luminosity for the absorption components) fitted between 0.5−2 keV luminosity as well as the power-law slope using the RGS data. Therefore, we can calculate the 0.5 and 2 keV luminosity and compare it to the predicted luminosity at these energies. The difference is more than 2 orders of magnitude: 140 and

250 for the 0.5 and 2 keV luminosity respectively. As the measured luminosity is corrected for the Galactic and intrinsic absorption measured in this spectrum, this difference cannot be explained by the neutral and ionised absorption in this source. Furthermore, as this is a high-resolution spectrum, excess absorption of any significance which is needed to reduce the difference between predicted and measured νL_X is excluded. Therefore, for this source absorption cannot explain the difference between the predicted and measured X-ray luminosity.

For PG 1001+054, PG 1114+445, PG 1411+442 listed by Brocksopp et al. (2006) and PG 2214+139 (also known as Mrk 304) there are more detailed studies available using the EPIC data. For PG 1411+442 only a neutral absorber is fitted, while for PG 1001+054, PG 1114+445 and PG 2214+139 a warm absorber model is fitted. Schartel et al. (2005) studied PG 1001+054 and derived a hydrogen column density of 19.2×10^{26} m^{-2} and log($\xi/10^{-9}$ Wm) = 2.7. Ashton et al. (2004) studied PG 1114+445 in detail, fitting a 2 component warm absorber and noting that the absorption parameters derived are very similar to the ones derived for NGC 3783 using a 2 component model. They measure 2 ionisation parameters: log($\xi/10^{-9}$ Wm)) = 0.83 and 2.57 and $N_H = 7.41\times10^{25}$ and 5.25×10^{26} m^{-2}, respectively. Piconcelli et al. (2005) found the same parameters as Schartel et al. (2005) for PG 1001+054 and fitted a simpler model to PG 1114+445, which we will not discuss here. In addition, Piconcelli et al. (2005) did study 1411+442, fitting the continuum spectrum with a neutral absorber with hydrogen column density of 2.3×10^{26} m^{-2}. Piconcelli et al. (2004) fitted a two component warm absorber model to PG 2214+139, measuring hydrogen column densities of 17×10^{25} and 89×10^{25} m^{-2} and ionisation parameters of 0.77 and 1.95. As is the case for PG 0050+124, Piconcelli et al. (2004) gives the unabsorbed X-ray luminosity for PG 2214+139. Finally, for PG 0844+349 EPIC spectra were studied in detail by Brinkmann et al. (2006) and Gallo et al. (2010). Brinkmann et al. (2006) concludes that there is possibly a detection of the Fe XXVI Lyα absorption line, but that the mass-loss rate is certainly less than 1 $M_\odot$yr^{-1}. Gallo et al. (2010) fits the different flux state spectra assuming the same continuum model holds and prefers a model with a power-law and blurred reflection component, where the normalisation and photon index of the power-law component is variable. In this model there is no absorption, but they cannot rule out a model with a variable absorber and no reflection component. The details of these warm absorber models, as well as for PG 0050+124, are listed in Table 3.

We fitted the absorber of these 5 PG quasars and determined the difference in 5 keV luminosity due to the absorber. In four cases the difference was minimal, a factor of 1.3, 1.1, 1.06, 1.2 and 2.25 for PG 0050+124, PG 1001+054, PG 1114+445, PG 1411+442 and PG 2214+139 respectively. The difference between predicted and measured 5 keV luminosity is a factor of 760, 9.7, 135 and 6.3, and is much larger than is explained by the fitted absorber. To test if further absorption could explain the luminosity difference, we modelled the hydrogen column density of an absorber required to have an unabsorbed 5 keV luminosity equal to that predicted. Note that due to the possible X-ray luminosity difference between when the radio data and the X-ray data were obtained, this hydrogen column density is not an exact number. However, it should give a conclusive result as to whether excess absorption is a possible explanation.

For all five sources we decided to add a neutral as well as ionised absorber to the fitted absorber model, as absorption due to a neutral gas has a higher optical depth, and therefore requires a less large hydrogen column density for the same amount of absorption. However, an ionised absorber is more likely if it comes from the wind. For PG 1114+445 the necessary column density is 0.25×10^{28} m^{-2} for a neutral absorber and 0.6×10^{28} m^{-2} for an ionised absorber with an ionisation parameter of 2.57, i.e. the same as the highly ionised component fitted by Ashton et al. (2004). Both these column densities are larger than the best fit values derived by Ashton et al. (2004) of 7.41×10^{25} and 5.25×10^{26} m^{-2}. Note that the neutral and ionised hydrogen column density we derive is in addition to the absorber fitted by Ashton et al. (2004). Therefore, excess absorption unlikely explains the difference between the measured and predicted luminosity in the case of PG 1114+445. For PG 2214+139 the extra neutral hydrogen column density is 0.6×10^{28} m^{-2}, larger than the total hydrogen column density of 0.1×10^{28} m^{-2} Piconcelli et al. (2004) derives. Assuming an ionised absorber with logξ = 1.95 (the high ionisation parameter) we find an extra hydrogen column density of 0.65×10^{28} m^{-2}. Again, this indicates that excess absorption is unlikely to explain the difference between predicted and measured 5 keV X-ray luminosity.

For PG 1001+054 the additional neutral hydrogen column density needed is 1.3×10^{28} m^{-2}, while for an ionised absorber with an ionisation parameter of 2.7 (Schartel et al. 2005) is 2.7×10^{28} m^{-2}. Even the hydrogen column density of the neutral absorber is high enough that this would indicate a marginally Compton-thick absorber. For PG 1411+442 we calculated the needed neutral hydrogen column density for the unabsorbed measured 5 keV luminosity to be 1.77×10^{28} m^{-2}, which is nearly 2 orders of magnitude more than measured and would make this also a marginally Compton-thick spectrum. As no ionised absorber was fit for this source by Piconcelli et al. (2005), we fitted an ionised absorber with an canonical ionisation parameter of 1.5 (log, 10^{-9} Wm), as we also did for the remaining PG quasars in our sample without detailed absorber modelling.

For all the PG quasars in our sample, we list in Table 2 the difference in 5 keV luminosity due to the neutral hydrogen column density derived by Brocksopp et al. (2006). Brocksopp et al. (2006) finds mostly upper limits to the neutral hydrogen column density due to an intrinsic absorber, and thus the difference in luminosity is mostly given by upper limits. In the same Table we list the hydrogen column density a neutral (ionised) absorber needs to have to equate the predicted and measured 2 and 5 keV luminosity. We chose to model the neutral hydrogen column density, as the ionisation parameter of the possible absorber is unknown, and because neutral gas is more efficient in absorbing X-ray radiation, thus this gives the minimum absorbing column density needed. For the ionised absorber we chose an ionisation parameter of 1.5 (log, 10^{-9} Wm), which is a rough average of the ionisation parameters observed in the well studied Seyfert 1 galaxies. The units for these modelled hydrogen column densities are in 10^{28} m^{-2}, where a column density higher than 1.5×10^{28} m^{-2} indicates a Compton-thick absorber (Matt, Pompilio & La Franca 1999). In modelling the source we used the 2−5 keV luminosity and power-law slope as given by Brocksopp et al. (2006) or used the detailed models available for the 4 sources discussed earlier. Fig. 5 shows the required versus measured column density of an X-ray absorber using the 5 keV luminosity. This figure does not include the 4 quasars with detailed absrober modelling.

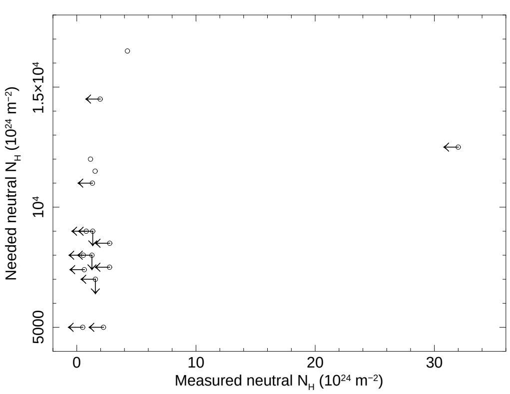
A recent study of nearby Seyfert 1 galaxies suggests that an absorber produced by a large scale, continuous radial flow from an accretion disc may have a density profile $n \propto r^{-\alpha}$ where $1 < \alpha < 1.3$ (Behar 2009). In particular, for the Seyfert galaxy NGC 5548 Steenbrugge et al. (2005) find that the observed X-ray spectrum

Table 3. The more detailed absorption model parameters: hydrogen column density and ionisation parameter, and the resulting difference in νL_X at 5 keV due to the intervening absorption. The next to last column lists the extra neutral hydrogen column density that is required to bring the predicted X-ray luminosity in agreement with the measured X-ray luminosity at 5 keV.

name	N_H^a	ξ^b	N_H^a	ξ	$\Delta\nu L_X$	$N_{H,5}^a$	reference
PG 0050+124	1.33	0	1.35	2.6	0	130[c]	Costantini et al. 2008
PG 1001+054	192	2.7	–	–	0.11	1300	Schartel et al. 2005
PG 1114+445	7.41	0.83	52.5	2.57	0.05	250	Ashton et al. 2004
PG 1411+442	23	n[d]	–	–	0.03	1770	Piconcelli et al. 2005
PG 2214+139	17	0.77	89	1.95	0	500	Piconcelli et al. 2004

[a] In 10^{25} m^{-2}.
[b] Log, and in 10^{-9} W m.
[c] Determined using the 2 keV luminosity, as for the RGS only the 0.5−2 keV luminosity is given.
[d] The fitted absorber was assumed neutral.

Figure 5. The measured neutral hydrogen absorption, or upper limit as listed by Brocksopp et al. (2006) versus the required neutral hydrogen column density for the predicted and measured 5 keV luminosity to be equal. We show all the PG quasars studied here, with the exception of PG 0050+124, PG 1001+054, PG 1114+445, PG 1411+442 and PG 2214+139.



can be described by a model with a continuous nonuniform distribution of density and ionisation parameter, suggesting that the warm absorber is not made up of clouds of ionised material in pressure equilibrium with the surrounding wind. Thus our absorption model assuming just a neutral or 1 ionisation parameter is overly simplified. In Seyfert 1 galaxies most of the gas is highly ionised (Steenbrugge et al. 2003), which is less efficient in absorbing the continuum. Therefore, even for the ionised absorber modelled here, the hydrogen column densities derived are lower limits, if the overall ionisation structure of the absorber in RQQs is similar to that in Seyfert 1 galaxies.

5 DISCUSSION

If the radio spectrum of radio-quiet quasars is produced in a free-free disc wind, the resultant bremsstrahlung X-ray emission must be absorbed because the observed X-ray spectrum is typically a power law, and not an exponential, and because the predicted X-ray luminosities for 0.5, 2 and 5 keV are much larger than those measured for all the PG quasars in our sample.

Studying Table 2, we find that the hydrogen column density needed to absorb the 2 and 5 keV luminosity are rather different. For the neutral (ionised) absorber the hydrogen column density is ~8 (4) times larger for the 5 keV luminosity than for the 2 keV luminosity, although the difference between predicted and measured luminosity is smaller at 5 keV. This difference could be explained if a more complicated absorber is present with most of the gas highly (i.e. >3 but <4 in log, 10^{-9} Wm) ionised. However, for such a high ionisation parameter, the required hydrogen column density required is further increased and becomes of order 2×10^{28} m^{-2}.

We find that most of the PG quasars would need to have an absorber that is nearly Compton-thick to explain the difference in luminosity between the predicted and measured 5 keV luminosity. Furthermore, to be able to fit the 2 and 5 keV luminosity a highly ionised absorber with very large column density is required. If the absorbers in RQQs have similar properties to those in the well studied Seyfert 1 galaxies, which one would expect to be the case considering their very similar X-ray properties such as the power-law slope and the temperature of the soft excess (see for instance Piconcelli et al. 2005), is very unlikely. Instead, from the derived hydrogen column densities we predict that PG quasar spectra should be very similar to Seyfert 2 galaxies, which show in high-resolution X-ray spectra an emission line spectrum in the soft X-ray band. Furthermore, they have a much flatter hard X-ray power-law photon index if the absorption is not fit or severely underestimated. From a statistical point of view it is unlikely that the PG quasar sample would be entirely consisting of those quasars with an obscuring torus along the line of sight, even-though the used sample is unlikely free from biases. Is there other evidence that this is not the case? For PG 0050+124, where Costantini et al. (2008) present a high-resolution X-ray spectrum, it can be ruled out that the source is similar to a Seyfert 2 galaxy, instead it shows a spectrum that is very similar to a weakly absorbed Seyfert 1 galaxy. This is the only quasar for which we have a high-resolution spectrum and for which we can exclude that extra absorption is the cause of the difference between the predicted and measured X-ray luminosity. The predicted 2 keV luminosity of this PG quasar is 250 times the measured luminosity, which is unlikely explained by luminosity variability. Therefore, for PG 0050+124 we are certain that the radio emission cannot be due to optically thin emission from a disc wind.

For the other quasars in our sample, we have to use a less direct method, and that is to compare the measured photon index and equivalent width of the Fe Kα emission line to those measured in Seyfert 1 galaxies and those in Seyfert 2 and Compton-thick AGN. The photon index for all but 2 of the studied PG quasars is not flat as would be expected if they had a near Compton-thick absorber, but varies around the photon indices measured in Seyfert 1 galaxies, i.e. $\Gamma = 1.9$ ($<\Gamma> = 2.1$ for the fitted quasars minus PG 1001+054 and PG 1411+442 see table 3 in Brocksopp et al. 2006). The equivalent width of the Fe Kα line stated by Brocksopp et al. (2006) is rather poorly determined and dependent on the assumed width of

the line, but is generally, with the exception of PG 1001+054 and PG 1411+442, consistent with being too small for a Compton-thick absorption model. Finally, we can use the UV measured equivalent width of the C IV 1549 Å absorption line. In our sample only 4 quasars show an C IV equivalent width that is larger than 1 Å, although a measurement was made in all but one of the 22 quasars. As there is generally a good correlation between UV and X-ray measured absorption, this would indicate that only 4 quasars in our sample have significant X-ray absorption. From the combination of the above arguments we conclude that for all but 2 of the studied PG quasars (PG 1001+054 and PG 1411+442) an absorber with a very large hydrogen column density can be ruled out as an explanation for the difference between predicted and measured X-ray luminosity.

Could PG 1001+054 and PG 1411+442, the 2 PG quasars with a flat hard X-ray power-law as measured by Brocksopp et al. (2006) have a nearly Compton-thick absorber? Signatures in medium-resolution spectra of Compton-thick spectra are a large equivalent width of the Fe Kα line and a flat hard energy spectrum, which in our case is the 2−5 keV spectrum. Indeed for these 2 PG quasars Brocksopp et al. (2006) finds a flat hard energy photon index: 0.14±0.4 and 0.35±0.1, respectively. For the broken power-law model fitted between 0.3−10 keV, the high energy photon indices for these 2 RQQs is 0.74 and 0.34, and thus still flat. Consistent with an origin of the flat photon indices due to absorption Schartel et al. (2005) and Piconcelli et al. (2005) do not derive such a flat power-law indices in their best fit model with absorber, instead they derive a photon index very similar to the canonical 1.9 measured in Seyfert 1 galaxies: 1.97 and 1.9 for PG 1001+054 and PG 1411+442, respectively.

A second signature is the equivalent width of the Fe Kα emission line, which ranges between <2 and < 10^6 and <428 and <706 eV (Brocksopp et al. 2006), and thus could be large, but is too poorly determined to be a constraint. Schartel et al. (2005) note that the spectrum of PG 1001+054 has a low signal-to-noise, and that the fitted model is a poor fit (χ = 15.6) to the data, but that a more complicated model is not warranted considering that only 12 energy bins remain after data binning. Therefore, no Fe Kα line was fitted. Piconcelli et al. (2005) does fit a narrow Fe Kα emission line and find that the emission is neutral, but does not mention the measured equivalent width of this line. However, as for PG 1001+054, this is a rather low signal-to-noise spectrum, and Piconcelli et al. (2005) claims that even fitting an ionised absorber is not warranted by the data quality.

PG 1001+054 is classified as a narrow line quasar based on the full-width-half-maximum (FWHM) of the Hβ line of 1740 kms^{-1} (Wills, Shang & Yuan 2000), indicating that the broad emission lines are more narrow, i.e. less than 2000 kms^{-1}, than for most type 1 AGN. This quasar is also classified as a broad absorption line (BAL)QSO, with strong UV absorption, and thus likely is severely absorbed in the X-ray band. Blustin et al. (2008) studied 5 X-ray selected BALQSO's and derived hydrogen column densities between 3.2×10^{26} m^{-2} for the one neutral absorber, and 4×10^{28} m^{-2} for an ionised absorber. The ionised hydrogen column densities are somewhat larger than the hydrogen column density we require for PG 1001+054 and PG 1411+442 to match the predicted 5 keV luminosity. PG 1411+442 shows strong UV absorption, and is with PG 1001+054 one of the 4 sources in our sample that has a C IV equivalent width larger than 1 Å. Therefore we conclude that P 1001+054 and PG 1411+442 likely harbour a nearly Compton-thick absorber, and that the difference between predicted and measured X-ray luminosity could be due to absorption. For a more conclusive result higher signal-to-noise X-ray spectra of these 2 sources need to be obtained.

There is another high-resolution X-ray spectrum taken with the high-energy transmission grating (HETG) on-board *Chandra* of the radio-quiet quasar, MR 2251-178, which however is not listed in the Palomar-Green catalogue. Gibson et al. (2005) fit the warm absorber with a column density of 2.37×10^{25} m^{-2} and an ionisation parameter of 0.02 (log 10^{-9} Wm). They also detect a high velocity outflow, however, this line was not observed in the XMM-*Newton* spectra (Kaspi et al. 2004) of the source, and is thus either very variable or a spurious detection. Kaspi et al. (2004) studying the high-resolution RGS spectrum of the same source fits the absorption with a 2 component model which have a column density of 3−6×10^{25} m^{-2} for the high ionisation component and 2×10^{24} m^{-2} for the low ionisation component. The derived column densities for this source are higher than the average column density derived for the PG quasars studied by Brocksopp et al. (2006), but similar to the column density derived by Costantini et al. (2008) for PG 0050+124 and smaller than the column density derived by Schartel et al. (2005); Ashton et al. (2004); Piconcelli et al. (2005, 2004) for PG 1001+054, PG 1114+445, PG 1411+442 and PG 2214+139, respectively.

So far we have assumed that the hard X-ray emission is directly due to the emission from a wind with $\tau \lesssim 1$. We have ignored the fact that the observed spectrum is a power-law and not an exponential, as predicted by Eq. 2. We have also ignored that likely at least part of the hard X-ray emission is due to Comptionised accretion disc photons. Indeed, if part of the hard X-ray emission does not originate in the wind, the luminosity difference that needs to be explained is even larger, and therefore the required absorber column densities will be larger. This would make an absorber as an explanation between the observed and predicted luminosities even less likely. We have further assumed that there is no redistribution of the X-ray luminosities, as caused by reflection. However, reflection is generally assumed to add an insignificant luminosity at 2 and 5 keV, and should therefore not greatly alter the column densities derived in this paper.

An added uncertainty in comparing radio and X-ray data taken years apart is the luminosity variability observed in the X-ray part of the spectrum. X-ray luminosity variability is random and therefore we expect as many sources that have a smaller X-ray luminosity than that predicted from the observed radio emission, than have a higher X-ray luminosity. The X-ray variability probably explains part of the difference in the derived hydrogen column densities. However, it cannot explain the over-predicted hydrogen column density in all the PG quasars studied.

Blustin & Fabian (2009) calculated the 1.4 GHz radio emission from the X-ray absorber measured in 5 nearby AGN. They estimate that the X-ray absorber is optically thick, and therefore use the formalism of Wright & Barlow (1975) to calculate the expected 1.4 GHz radio emission from the X-ray observed absorber, assuming a spherically symmetric wind. From the comparison between the calculated radio emission and the observed radio emission they derive the upper limits to the volume filling factor of the absorber. These are upper limits, because any 1.4 GHz emission from the UV part of the wind, the base of the jet, the accretion disc or the host galaxy is ignored. The upper limits derived range between 10^{-4} and 0.5, indicating that at least is some AGN the volume filling factor of the absorber is small. For at least 1 AGN, NGC 3783, the radio emission cannot be explained by the observed absorber components. It therefore seems unlikely that the radio and X-ray emission

solely come from the same wind, whether optically thin or thick, as detected in the UV and X-ray through absorption.

6 CONCLUSIONS

We have tested the theory that bremsstrahlung emission from an optically thin disc wind can explain the radio emission in radio-quiet quasars, by comparing the predicted X-ray emission at 0.5, 2 and 5 keV to the measured X-ray luminosities at these energies. We have modelled the difference in luminosity as due to a neutral or ionised absorber, likely formed in the same disc wind, but further out. We find that all the disc winds in the PG quasars studied would need to have an absorbing hydrogen column density that is nearly Compton-thick. For 20 of the 22 PG quasars we studied we can exclude such a large hydrogen column density from the existing medium-resolution X-ray spectra and the small C IV equivalent width measured in those RQQs. For one RQQ, PG 0050+124, there is a high-resolution spectrum, which is clearly inconsistent with the required extra absorption. For the remaining 2 RQQs: PG 1001+054 and PG 1411+442 we conclude that the spectra are consistent with the necessary absorption to explain the difference between predicted and measured X-ray luminosity, and that thus in these 2 quasars emission from a disc wind could explain the radio emission from the nucleus.

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